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An adaptive large neighborhood search for a vehicle routing problem with cross-dock under dock resource constraints

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1 Introduction

Cross-docking is a rather recent distribution strategy, in which goods are brought from suppliers to an intermediate transshipment point, the so-called cross-dock, where they can be transferred to another vehicle before being delivered. Transfers are done based on consolidation opportunities. There is little to no storage capacity at the cross-dock, thus cutting down inventory holding costs compared to traditional distribution centers. It can also help reducing distribution costs by making it easier to consolidate shipments to full truck loads compared to point-to-point deliveries. Cross-docking has been successfully applied to several sectors, the canonical example being Walmart for which it is said to have been the key to the growth of the retailer in the 1980s.

A lot of cross-docking related problems exist such as : location, assignment of trucks to doors, inner flow optimization or routing (see [1, 11] for surveys on cross-docks). In particular, the *vehicle routing problem with cross-dock* (VRPCD) consists in designing routes to pick up and deliver a set of transportation requests at minimal cost using a single cross-dock. Trucks start by collecting items, then return to the cross-dock where they can offload some requests and load others before starting their delivery trips. The exchange of goods at the cross-dock is a consolidation process whose aim is to minimize the total delivery cost by collaboration between vehicles.

We propose a solution methodology, based on a combination of adaptive large neighborhood search (ALNS) and constraint programming, for a variant of the vehicle routing problem with cross-dock that takes into account time windows on pickup and delivery points, and capacity constraints on the number of vehicles that can be simultaneously processed at the cross-dock.

2 The vehicle routing problem with cross-dock

2.1 Literature review

Lee et al. [5] introduced a VRPCD variant in which all vehicles have to arrive simultaneously at the cross-dock. They proposed an exact formulation and developed a tabu-search. Wen et al.[12] extended the problem by adding time windows on nodes and relaxing the constraint of simultaneous arrival at the cross-dock for all vehicles, only imposing precedence constraints based on the consolidation decisions. They presented a MIP formulation of that extension, and proposed a tabu-search embedded in a adaptive memory procedure. They solved instances with up to 200 requests originated from real-life data. With an adaptive tabu-search, Tarantilis [10] improved the best-known solutions, and also tested other network configurations. Petersen and Ropke [8] created a parallel ALNS to solve a real life variant of the VRPCD with time windows, optional cross-dock return and multiple trips per day, which is tested on instances between 585 and 982 requests. Dondo and Cerda [2] considered a variant of the VRPCD in which they modeled each door at the cross-dock individually (handling speeds, travel times to other doors, ...) and with a smaller number of doors than the number of trucks. They proposed a solving methodology based on a MILP formulation and a sweep heuristic and they solved instances with up to 70 requests, and a doors-to-vehicle ratio ranging between $1/3$ and $1/2$. Closely related problems are problems with transfers such as the *pickup and delivery problem with transfers* (PDPT) [6], and problems with *operations synchronization* and *resources synchronization*, as described in [3], such as the *two-echelon multiple-trip vehicle routing problem with satellite synchronization* [4].

2.2 The VRPCD-DR

We introduce the *vehicle routing with cross-dock under dock resource constraints* (VRPCD-DR). We consider a cross-dock c , a set of requests R , and a homogeneous fleet of vehicles V , each of capacity q and based at o . Each request r has to be picked up at its pickup location p_r within its pickup time window, and has to be delivered at its delivery location d_r within its delivery time window. Each vehicle starts at o , then goes to several pickup locations, arrives at the cross-dock where it unloads/reloads some requests, then visits delivery locations and eventually returns to o .

The cross-dock is modeled as an exclusive cross-dock: each dock door is either exclusively dedicated to unloading or loading tasks, and this assignment can not be modified. The number of docks that can be processed simultaneously is limited : c_u unloading docks (resp. c_r reloading docks). If a vehicle k has to unload and reload requests, then as shown in figure 1 the time it spends at the cross-dock can be divided into four periods.

- Preparation for unloading. During this period the vehicle is docking at an inbound door, so it does not require workers. The duration of this period is fixed δ_u .
- Unloading of requests. The duration of this period depends on the quantity of products to unload, so for a vehicle k : $\sum_{i \in \text{Unload}(k)} q_i \times s_u$, where s_u corresponds to the unloading speed in quantity per time unit, and does not depend on the vehicle. All requests become available for reloading at the end of this period. Requests not being transferred remain in the vehicle.
- Preparation for reloading. During this period the vehicle is docking at an outbound door, it does require workers. The duration of this period is fixed δ_r .
- Reloading of requests. Similarly to unloading, the duration of this period depends on the quantity of products to reload, so for a vehicle k : $\sum_{i \in \text{Reload}(k)} q_i \times s_r$, where s_r corresponds to

the reloading speed in quantity per time unit, and does not depend on the vehicle. All requests to reload must have been unloaded before the beginning of the reloading operation.

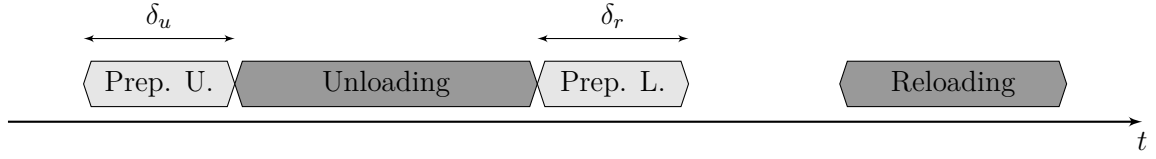


Figure 1: Example of a time chart for a vehicle unloading and reloading at the cross-dock. Vehicle has to wait to be reloaded either because of a late arrival of some products to reload, or because the cross-dock is being used at its full reloading capacity

Note that a vehicle has to go to the cross-dock even if it does not unload nor reload any requests there.

Solving the VRPCD-DR involves finding $|V|$ routes, and a schedule for them, such that the capacity and time-related constraints are satisfied, while minimizing the routing cost.

The routing problem in the VRPCD-DR is an extension of the vehicle routing problem, which is known to be NP-Hard, while the scheduling problem encompasses the scheduling on two parallel machines (provided there is more than one dock on one side), which is also NP-Hard.

3 Solution approach

The general solution approach we used is an ALNS, in which we embed a constraint programming model to solve the scheduling problem at the cross-dock. We are faced with two challenges: first keeping a reasonable runtime given that the scheduling subproblem is NP-Hard, and second developing heuristics that take into account the resource constraints. For efficiently solving the scheduling problem, we compute for each truck the earliest arrival time at the cross-dock and the latest departure time from the cross-dock that do not violate any time window on pickup and delivery points. This is done using Savelsbergh's forward time slacks [9]. Yet calling the constraint programming solver for every candidate insertion would be very time consuming. So we have adapted the efficient feasibility check technique of Masson et al.[7] (also used in [4]), which is valid for the non-resource constrained problem. The constraint programming solver is used only as last resort. This technique contributes to significantly reduce the runtime of the algorithm. For recreate heuristics we have created a special version of the regret insertion heuristics which is given a maximum number of candidate insertions that can be checked for feasibility. Regarding ruin heuristics, we have adapted methods from the problem with transfers, as well as created methods specifically taking into account the resource constraints at the cross-dock.

Our algorithm is tested on the instances of Wen et al. [12] for which we have added resource constraints. We study the impact of the number of docks on the solution: change in the number of vehicles and/or in the cost.

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